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JPRS L/8920

13 February 1980

# USSR Report

## EARTH SCIENCES

(FOUO 2/80)

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# USSR REPORT

## EARTH SCIENCES

(FOUO 2/80)

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## I. METEOROLOGY

UDC 551.576+551.577+551.578+551.508+551.511

### ARTICLES ON CLOUD PHYSICS AND ARTIFICIAL MODIFICATION

Moscow TRUDY UKRAINSKOGO NAUCHNO-ISSLEDOVATEL'SKOGO GIDROMETEOROLOGICHESKOGO INSTITUTA: FIZIKA OBLAKOV I AKTIVNYYE VOZDEYSTVIYA (Transactions of the Ukrainian Scientific Research Hydrometeorological Institute: Cloud Physics and Artificial Modification) in Russian Issue 170, 1979 signed to press 10 Jul 78 pp 2, 127

[Annotation and table of contents from collection of articles edited by Doctor of Physical and Mathematical Sciences M. V. Buykov and Candidate of Geographical Sciences T. N. Zabolotskoy, Moskovskoye Otdeleniye Gidrometeoizdat, 136 pages]

[Text] This collection of papers gives data from field observations of clouds. The papers present the results of numerical modeling of the processes of formation of precipitation in clouds of different forms. Also given are the results of laboratory investigations of reagents for the modification of clouds and fogs. The collection is intended for specialists in the field of cloud physics and artificial modification, meteorologists and gradulate students.

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ARTICLES ON METHODS FOR METEOROLOGICAL OBSERVATIONS

Leningrad TRUDY GLAVNOY GEOFIZICHESKOY OBSERVATORII: METODIKA METEOROLOGICHESKIKH NABLYUDENIY (Transactions of the Main Geophysical Observatory: Methods for Meteorological Observations) in Russian Issue 416, 1978, signed to press 14 Sep 78 pp 2, 114

[Annotation and table of contents from collection of articles edited by Candidate of Physical and Mathematical Sciences D. P. Bespalov, Gidrometeoizdat, 120 pages]

[Text] Annotation. This collection of articles contains studies relating to the improvement of methods for carrying out meteorological and heat balance observations, evaluation of the reliability of the results and use of these evaluations in the methodological direction of the network of stations. The collection is intended for specialists in the Administrations of the Hydrometeorological Service (Hydrometeorological Observatories) and the scientific research institutes of the Main Administration of the Hydrometeorological Service concerned with the problems involved in the formulation and carrying out of meteorological observations, generalization and monitoring of the quality of the results. The articles on the improvement of measurement methods contain useful material for specialists concerned with the development of instruments. In general the collection is an aid for students and teachers in colleges with a meteorological field of specialization.

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STATISTICAL ANALYSIS OF HYDROMETEOROLOGICAL PROCESSES USING A COMPUTER

Leningrad TRUDY GLAVNOY GEOFIZICHESKOY OBSERVATORII: STATISTICHESKIY ANALIZ GIDROMETEOROLOGICHESKIKH PROTSESSOV S POMOSHCH'YU EVM (Transactions of the Main Geophysical Observatory: Statistical Analysis of Hydrometeorological Processes Using a Computer) in Russian Issue 409, 1978, signed to press 20 Oct 78 pp 2-138

[Annotation and table of contents from collection of articles edited by Candidate of Physical and Mathematical Sciences B. M. Il'in and Doctor of Physical and Mathematical Sciences I. I. Polyak, Gidrometeoizdat, 144 pages]

[Text] The authors of these articles examine the results of analysis of hydrometeorological observations made using an electronic computer. The articles describe programs for the harmonic analysis of meteorological fields. The problems involved in the storage of data on a technical carrier are examined. The collection is intended for scientific workers, graduate students and students using electronic computers for the processing and analysis of observations.

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METROLOGICAL STUDIES AND PROBLEMS IN CONTROL TESTING OF METEOROLOGICAL INSTRUMENTS

Leningrad TRUDY GLAVNOY GEOFIZICHESKOY OBSERVATORII: METROLOGICHESKIYE ISSLEDOVANIYA I VOPROSY POVERKI METEOROLOGICHESKOY APPARATURY (Transactions of the Main Geophysical Observatory: Metrological Studies and Problems in Control Testing of Meteorological Instruments) in Russian Issue 414, 1978, signed to press 11 Aug 78 pp 2, 116

[Annotation and table of contents from collection of articles edited by Candidate of Technical Sciences N. P. Fateyev, Gidrometeoizdat, 120 pages]

[Text] Annotation. The articles in this collection of papers are devoted to an analysis of the state of meteorological measurements, the problems involved in the introduction of local check schemes and metrological investigation of measuring instruments. The articles also examine the metrological properties of working and sample measuring instruments, in particular, the results of experimental investigations of the accuracy parameters of aspiration psychrometers, and also give descriptions of some new instruments and measuring complexes. The collection is intended for specialists working in the field of support of meteorological and geophysical measurements and can be useful for persons developing and operating instrumentation for the mentioned purpose, graduate students, instructors and students at colleges and instructors and students at meteorological technical schools.

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II. OCEANOGRAPHY

UDC 551.465.41

# CHARACTERISTICS OF SMALL-SCALE TURBULENCE IN THE OCEAN THERMOCLINE

Moscow IZVESTIYA AKADEMII NAUK SSSR in Russian Vol 15, No 10, 1979 pp 1060-1066

[Article by V. S. Belyayev, I. D. Lozovatskiy and R. V. Ozmidov, Institute of Oceanology, submitted for publication 22 August 1978]

Abstract: The authors analyze data from measurements of the vertical microstructure of the current velocity and conductivity fields and the accompanying local background conditions in the upper 300-m layer of the ocean. Estimates of the rate of evening-out of temperature inhomogeneities, rate of dissipation of turbulent energy, Cox number, turbulent heat flux, buoyancy scale, coefficients of turbulent heat exchange and exchange of momentum, and gradient Richardson number in the ocean thermocline were obtained. In the range of change in the Richardson number Ri from 0.12 to 1.2, prevailing under the measurement conditions, the dependence of the Cox number and the ratio of the coefficients of turbulent exchange of heat and momentum are approximated by power-law dependences on Ri with exponents (-0.8) and (-1) respectively.

[Text] The statistical characteristics of small-scale turbulence in the ocean thermocline are essentially dependent on the local parameters of stratification of the medium such as the local gradients of density and current velocity. Under the influence of strong stable stratification, characteristic for the ocean thermocline, there can be an appreciable decrease in the intensity of current velocity fluctuations in the thermocline in comparison with the upper mixed layer. The statistical regime of small-scale fluctuations of hydrophysical fields in such cases will differ from the regime of well-developed turbulence at high Reynolds numbers; in particular, in the spectra of fluctuations of velocity u' and temperature T' there may be no inertial and inertial-convective scale intervals. An experimental investigation of the statistical characteristics of such undeveloped turbulence and the dependence of these characteristics on the local parameters of medium stratification was undertaken on the 19th voyage of the scientific research ship "Dmitriy Mendeleyev" [1].

In the Philippine Sea measurements were made of the microstructure of the fields of current velocity, conductivity of sea water and the fine structure of the temperature field from the surface to a depth of 300 m using a probe fabricated in the Special Design Bureau of Oceanological Equipment (SDB OT) of the Institute of Oceanology imeni P. P. Shirshov USSR Academy of Sciences. The probe was supplied with an electromagnetic sensor of velocity fluctuations $u'$, a hydroresistor sensor of conductivity fluctuations $\sigma'$, a thermistor sensor for mean temperature T with a time constant of 0.3 sec, a standard pressure sensor DDV-100 and a sensor of vibrational accelerations. The level of the inherent noise in the velocity fluctuations channel was 0.08 $cm \cdot sec^{-1}$, for the conductivity channel -- $3.4 \cdot 10^{-7}$ $ohm^{-1} \cdot cm^{-1}$. A reciprocal analysis of the vibration signal with the $u'$ and $\sigma'$ signals indicated absence of an appreciable influence of vibration of the measuring line on the readings of the velocity and conductivity fluctuation sensors. The measurements were made from a drifting ship in a vertical sounding regime -- with a mean velocity of movement of the probe 1.4 $m \cdot sec^{-1}$. Below we present an analysis of the data obtained as a result of four successive soundings carried out with an interval of 12 minutes between them.

The mean hydrological conditions in the measurement region were characterized by the presence of an upper mixed layer to a depth of 70 m. In the thermocline (70-300 m) the mean temperature gradient $T_z$ was 0.07°$C \cdot m^{-1}$ and in the vertical distribution of salinity there was a maximum at a depth of 150 m; the salinity gradient $S_z$ in the layer from 70 to 150 m was 0.006°/oo$\cdot m^{-1}$, and in the layer from 150 to 300 m -- 0.004°/oo$\cdot m^{-1}$. The mean density gradient $\rho_z$ gradually increased with depth and attained maximum values $\rho_z = 2.6 \cdot 10^{-5}$ $g \cdot cm^{-3} \cdot m^{-1}$ in the layer from 100 to 200 m.

A distinguishing characteristic of the vertical profiles of microstructure of the investigated fields was their reproducibility, in general, with repeated soundings. In the upper mixed layer, except for the surface layer with a thickness of 10-15 m in individual soundings, the magnitude of the $\sigma'$ fluctuations was considerably less than in the thermocline, where, however, in quasi-isothermic layers there was also a marked decrease in the intensity of conductivity fluctuations. The standard deviation of fluctuations of current velocity, whose maximum was in the surface layer and which is evidently attributable to the influence of wind mixing, in the thermocline had values not exceeding 0.2 $cm \cdot sec^{-1}$. Due to the weak intensity of current velocity fluctuations in the thermocline (the $u'$ signal level did not greatly exceed the level of the inherent noise in the measuring channel) a spectral analysis of the $u'$ signal was not of great interest.

The spectral densities of conductivity fluctuations $E_\sigma(k)$ were computed using individual quasi-homogeneous segments of the $\sigma'(z)$ record in the thermocline. Figure 1 shows examples of typical spectral curves $E_\sigma(k)$ in the

| Номер зондирования и реализации 1 | Δz, м | $\overline{T}_z \cdot 10^4$, °C·см$^{-1}$ | $\varepsilon_T \cdot 10^8$, °C$^2$·с$^{-1}$ 2 | $\varepsilon_u \cdot 10^4$, см$^2$·с$^{-3}$ | C | $K_T \cdot 10^3$, см$^2$·с$^{-1}$ | $Q \cdot 10^6$, кал·см$^{-2}$·с$^{-1}$ 3 | $l_s$, см | $L_*^3$, см | $K_u \cdot 10$, см$^2$·с$^{-1}$ 2 | Ri |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,1 | 116-146 | 7,0 | 1,4 | 1,0 | 3,3 | 4,8 | 3,2 | 8,3 | 18 | 7,5 | 0,78 |
| 1,2 | 153-183 | 9,0 | 1,9 | 0,7 | 2,7 | 3,9 | 3,3 | 7,6 | 14 | 6,8 | 1,2 |
| 1,3 | 196-230 | 6,0 | 1,4 | 1,6 | 4,5 | 6,5 | 3,7 | 6,2 | 32 | 5,3 | 0,29 |
| 1,4 | 254-272 | 5,2 | 1,4 | 1,2 | 6,0 | 8,6 | 4,3 | 7,1 | 35 | 6,2 | 0,39 |
| 2,1 | 100-124 | 5,0 | 1,7 | 1,2 | 7,9 | 11,0 | 5,4 | 6,6 | 25 | 6,5 | 0,40 |
| 2,2 | 128-154 | 6,5 | 1,7 | 2,7 | 4,7 | 6,7 | 4,1 | 7,6 | 32 | 6,9 | 0,25 |
| 2,3 | 156-183 | 8,6 | 2,2 | 1,6 | 3,5 | 5,0 | 4,1 | 7,1 | 22 | 6,4 | 0,49 |
| 2,4 | 185-218 | 6,0 | 1,6 | 1,8 | 5,2 | 7,4 | 4,2 | 6,6 | 32 | 5,5 | 0,27 |
| 2,5 | 220-258 | 4,0 | 1,8 | 3,0 | 13 | 19,0 | 7,2 | 6,6 | 62 | 6,3 | 0,12 |
| 2,6 | 262-290 | 3,6 | 1,6 | 1,8 | 14 | 21,0 | 7,1 | 6,6 | 52 | 5,9 | 0,17 |
| 3,1 | 107-136 | 7,5 | 1,5 | 1,2 | 3,2 | 4,5 | 3,2 | 5,9 | 19 | 5,4 | 0,49 |
| 3,2 | 146-170 | 8,9 | 1,8 | 1,0 | 2,6 | 3,7 | 3,2 | 5,9 | 16 | 5,3 | 0,71 |
| 3,3 | 177-204 | 7,3 | 1,8 | 1,5 | 4,0 | 5,6 | 3,9 | 5,9 | 25 | 4,9 | 0,35 |
| 3,4 | 209-237 | 5,0 | 1,4 | 1,5 | 6,4 | 9,2 | 4,4 | 5,9 | 37 | 4,9 | 0,24 |
| 3,5 | 255-280 | 4,5 | 1,9 | 2,0 | 11 | 15,0 | 6,6 | 5,5 | 50 | 4,7 | 0,16 |
| 4,1 | 117-140 | 8,0 | 1,6 | 2,1 | 2,9 | 4,1 | 3,2 | 7,1 | 24 | 12,1 | 0,69 |
| 4,2 | 187-216 | 8,7 | 2,0 | 1,1 | 3,2 | 4,6 | 3,8 | 7,1 | 20 | 6,4 | 0,70 |
| 4,3 | 224-254 | 5,0 | 1,4 | 1,0 | 6,3 | 9,0 | 4,3 | 7,1 | 31 | 5,9 | 0,45 |
| 4,4 | 263-291 | 3,6 | 1,5 | 1,9 | 13 | 19,0 | 6,6 | 6,2 | 58 | 6,3 | 0,18 |

KEY:

1. Number of sounding and reading
2. ... sec$^{-1}$
3. ... cal·cm$^{-2}$·sec$^{-1}$

thermocline. The depth intervals for which the $E_\sigma(k)$ spectra were computed and the mean values of the temperature gradients within these layers are given in the table. A distinguishing characteristic of all the $E_\sigma(k)$ spectral curves is a marked change in the steepness of dropoff of the spectra with an increase in wave number at scales $\lambda \approx 7$ cm. In the range of scales from 70 to 7 cm the slope of the approximating straight lines to the x-axis at a logarithmic scale is close to -3, and when $\lambda \leqslant 7$ cm -- to -1. There is no sector of wave numbers in which $E_\sigma(k)$ is proportional to $k^{-5/3}$. We note that in the measurements by Gregg [2], made in different regions of the Pacific Ocean, the slope of the spectra of temperature fluctuations $E_T(k)$ in the range of wave numbers which we considered in individual cases also changed from -3 to -1, but this change in slope occurred, as a rule, at scales of several tens of centimeters. Henceforth, neglecting the contribution of salinity fluctuations to conductivity fluctuations, that is, assuming that the conductivity fluctuations are caused only by temperature fluctuations, we will interpret the $E_\sigma(k)$ spectra as the spectra of temperature fluctuations $E_T(k)$, scaled in appropriate fashion into units °C$^2$·cm.

The existence of a range of scales where $E_T(k) \sim k^{-1}$ in the $E_T(k)$ spectra in the region of large wave numbers can mean that turbulent fluctuations in the thermocline with scales $\lambda < 7$ cm were in a viscoconvective interval regime, for which, in accordance with [3],

$$E_T(k) = \beta_B \varepsilon_T (\nu/\varepsilon)^{1/2} k^{-1}, \qquad (1)$$

where the universal constant $\beta_B \approx 2$ [4]; $\varepsilon$ is the rate of dissipation of turbulent energy; $\varepsilon_T$ is the rate of evening-out of temperature inhomogeneities; $\nu$ is the kinematic coefficient of molecular viscosity ($\nu \approx 0.01$ $cm^2 \cdot sec^{-1}$). With known $\varepsilon_T$ values, using expression (1) it is possible to determine the $\varepsilon$ value. The $\varepsilon_T$ value was estimated using the formula $\varepsilon_T = 6\chi\overline{(\partial T'/\partial z)^2}$, where $\chi$ is the coefficient of molecular thermal conductivity ($\chi \approx 1.4 \cdot 10^{-3} cm^2 \cdot sec^{-1}$); the line at the top denotes the averaging operation. The computed $\varepsilon_T$ and $\varepsilon$ values are given in the table. The mean $\bar{\varepsilon}_T$ value for four soundings and the standard deviation of individual $\varepsilon_T$ values from the mean $s_{\varepsilon T}$ were $1.7 \cdot 10^{-8}$ and $0.2 \cdot 10^{-8}$ °$C^2 \cdot sec^{-1}$ respectively. For $\varepsilon$ the corresponding $\bar{\varepsilon}$ and $s_\varepsilon$ values were $1.6 \cdot 10^{-3}$ and $0.6 \cdot 10^{-3} cm^2 \cdot sec^{-3}$.

Then we estimated the values of an important parameter of microstructure of the temperature field in the thermocline -- the Cox number $C = \overline{(\partial T'/\partial z)^2} / (\partial \bar{T}/\partial z)^2$, which characterizes the degree of "microstructural activity" of the temperature field, and in the absence of advective processes -- also the coefficient of turbulent heat exchange $K_T = \chi C$ [5]. The author of [2] obtained estimates of the Cox number C using data from measurements of microstructure of the temperature field in the main thermocline in three different regions of the Pacific Ocean and during different seasons. The range of C change in [2] is (1-240). The mean value and mean square scatter of individual C values according to our data are 6.2 and 3.8 respectively. Taking into account that the investigated ranges of scales of microstructure of the temperature field in both cases are approximately identical, the conclusion can be drawn that the C and $K_T$ values cited in the table evidently indicate a weakness of turbulent mixing in the thermocline in the observation region. The vertical heat flow can be computed using the formula $Q = c_p \rho K_T \bar{T}_z$, where $c_p$ is the specific heat capacity at constant pressure; $\rho$ is the density of sea water. In the computations it was assumed that $c_p = 0.93$ $cal \cdot g^{-1} \cdot degree^{-1}$. Estimates of Q (see table) vary from $3.2 \cdot 10^{-6}$ to $7.2 \cdot 10^{-6}$ $cal \cdot cm^{-2} \cdot sec^{-1}$, that is, the turbulent heat flow in the thermocline in our case varied with depth in a relatively small range.

It should be remembered that since in the considered range of scales the dissipation spectra $k^2 E_T(k)$ do not attain maxima, the determined estimates of the rate of evening-out of the temperature inhomogeneities, and accordingly, the rate of dissipation of turbulent energy and the Cox number, can be regarded only as lower estimates of the corresponding values.

The marked change in the slope of the $E_T(k)$ spectral curves in the considered range of scales can be caused by the generation of inhomogeneities in the thermocline with vertical scales $\ell_s$ close to the scales at which there is a "bend" in the $E_T(k)$ spectra. In this case the $\ell_s$ scale must be regarded as the local external scale of turbulence $\ell_0$. We note that the influence of

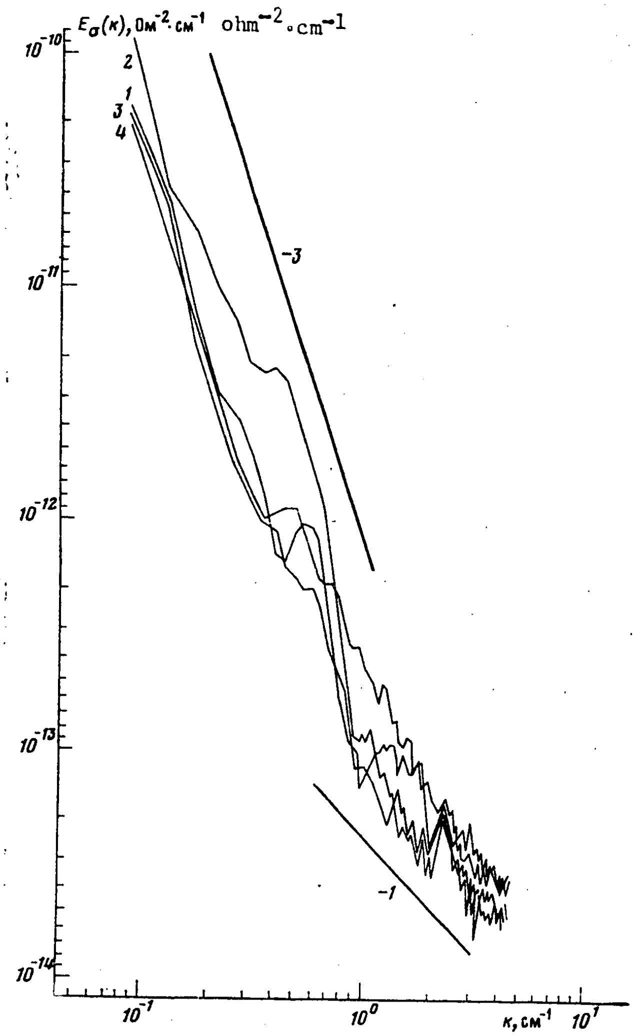


Fig. 1. Spectral densities of fluctuations of conductivity in thermocline: in layer 117-140 m (1), 187-216 m (2), 224-254 m (3), 263-291 m (4).

buoyancy forces is not reflected in this case in the regime of turbulent fluctuations. In actuality, fluctuations with the scales $\lambda$ are under the influence of buoyancy forces if $\lambda > L_*^0 = (\varepsilon/N^3)^{1/2}$, where $N = [(g/\rho)(d\rho/dz)]^{1/2}$ is the Väisälä frequency, computed in our case from the temperature gradients in the considered layers on the assumption of smallness of the contribution of the salinity gradient to the density gradient. The values of the buoyancy scale $L_*^0$ vary from 14 to 60 cm (see table) and accordingly exceed the $\ell_0$ values. The statistical regime of fluctuations of the temperature field with scales $\lambda > {}_0$, characterized by the spectrum $E_T(k) \sim k^{-3}$, is evidently formed under the influence of internal waves which were discovered in the thermocline during the course of the experiments [6]. However, the generation of microstructural temperature inhomogeneities with scales of about $\ell_0$ could be caused by the appearance of wave-eddy turbulence in the thermocline [7]. As follows from visual observations of the destruction of short internal waves in density layers, the scale of the eddies $\ell$ eddy generated in this case is approximately an order of magnitude less than the amplitude A of the initial wave. The characteristic values for A and $\ell_{eddy}$ in [7] were close to 1 m and 10 cm respectively. The scale $\ell_0 = \ell_S \approx 7$ cm, in which a "bend" of the $E_T(k)$ spectra is observed, has values close to $\ell_{eddy}$, which makes it possible to postulate the generation of microstructural inhomogeneities of the temperature field by wave-eddy turbulence in the considered case.

Assuming $\ell_0$ to be the local external turbulence scale and knowing the dispersion of current velocity fluctuations $b = s_u^2$, it is possible to determine the coefficient of turbulent exchange of momentum $K_u = \ell_0\sqrt{b}$. As a result of the low level of the u' signal the estimates obtained for $K_u$ (see table) must be regarded as upward estimates since the minimum values of the intensity of current velocity fluctuations b are determined by the apparatus noise level. The ratio of the coefficients of turbulent heat exchange and exchange of momentum $\alpha = K_T/K_u$ is considerably less than unity and varies in a rather wide range from $0.34 \cdot 10^{-2}$ to $3.56 \cdot 10^{-2}$. It is known that with an increase in stability, characterized by the local Richardson number $Ri = N^2/U_z^2$, where $U_z$ is the mean vertical gradient of current velocity, the $K_T/K_u$ ratio has a tendency to a decrease. The author of [8] proposed the following formula for describing the dependence $\alpha$(Ri) in the stratified boundary layer with a constancy of the fluxes of heat and momentum:

$$\alpha=\alpha_0(1-Rf/Rf_{кр})/(1-Rf)^2, \qquad (2)$$

[KP = cr] where $\alpha_0$ is the $\alpha$ value with a stratification close to neutral; $Rf = \alpha Ri$ is the dynamic Richardson number and $Rf_{cr}$ is its critical value, that is, with $Rf < Rf_{cr}$ the turbulence is nonattenuating. The values of the local Richardson number Ri were computed using the formula $Ri = Rf/\alpha$, whereas the Rf value was determined from the equations for the balance of turbulent energy and the intensity of temperature fluctuations for stationary, horizontally homogeneous turbulence [9]:

$$Rf=\frac{\varepsilon_T\beta}{\varepsilon\overline{T}_z+\varepsilon_T\beta Rf_{кр}^{-1}}, \qquad (3)$$

where $\beta$ is the buoyancy parameter, equal to ga; g is the acceleration of gravity; a is the coefficient of thermal expansion of sea water. In computations using formula (3) the $Rf_{cr}$ value was assumed equal to 0.05 [10].

The estimates of the local Richardson number are given in the table. The maximum value Ri = 1.2 was noted during the first sounding in the depth range 153-183 m. In the layer 250-290 m the Ri value in three out of four cases was less than the critical value $Ri_{cr} = 0.25$ for a steady plane-parallel flow, which in principle could lead to the development of hydrodynamic instability in this layer.

We note that parallel with microstructural measurements in the layer 250-290 m we carried out measurements of current velocity relative to the drifting vessel using the Doppler effect accompanying the scattering of ultrasound [11]; these made it possible to obtain direct estimates of the vertical gradients of current velocity $U_z$. The local Richardson numbers computed using these data for the depth range 250-290 m were equal to 0.20-0.38, which is in good agreement with the Ri estimates cited in the table for the considered layer. Therefore, the Ri estimates obtained using the formula $Ri = Rf/\alpha$ and expressions (3), in our opinion, are entirely representative and make it possible to examine the dependence between individual statistical characteristics of turbulence and the Richardson number.

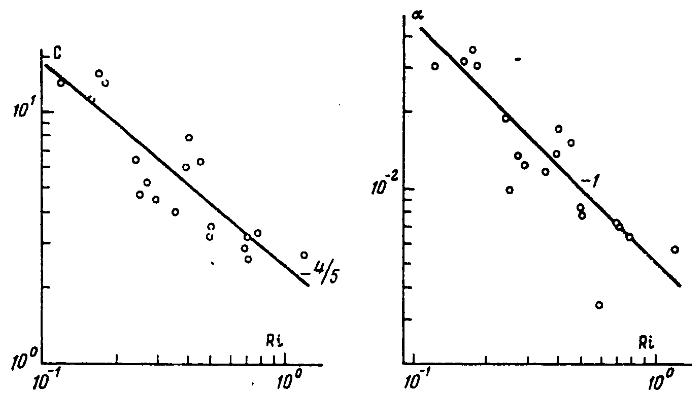


Fig. 2. (left) Dependence of the Cox number on the local Richardson number.
Fig. 3. (right) Dependence of the ratio of the coefficients of turbulent exchange of heat and momentum on the Richardson gradient number.

Figure 2, on a logarithmic scale, shows a graph of change in the Cox number C as a function of the local Richardson number. The experimental points can be approximated by the linear function lg C = lg A - n lg Ri, where A and n are some constants. The correlation coefficient between lg C and lg Ri was equal to -0.87 and the A and n values were equal to 2.5 and 0.8 respectively; for the slope n the 95% confidence interval is equal to 0.6-1.0. Thus, in the considered range of change in the Richardson number the dependence of the Cox number C on Ri can be represented by the formula

$$C = 2{,}5Ri^{-0{,}8}.$$

In conclusion we will discuss the important problem of the dependence of the ratio of the coefficients of turbulent exchange $\alpha = K_T/K_u$ on the Richardson gradient number. The curve of the dependence $\alpha$(Ri) in [10] computed on the basis of formula (2) for $\alpha_0 = 1$ and $Rf_{cr} = 0.05$, with $Ri \geqslant 0.2$, can be approximated by the hyperbolic curve $\alpha = C_1 Ri^{-1}$ ($C_1$ is a constant). The values of the parameters $\alpha_0$ and $Rf_{cr}$ were selected in [10] from the condition that the curve of the dependence $\alpha$(Ri) best corresponded to the available empirical data, obtained for the most part under laboratory conditions. Figure 3, in logarithmic coordinates, represents the experimental data on $\alpha$(Ri), which in the entire considered range of change in the gradient Richardson number $0.12 \leqslant Ri \leqslant 1.2$ are described well by the dependence $\alpha \sim Ri^{-1}$. According to our data, the value of the proportionality factor was somewhat less than in [10]. It is known that the wave movements arising in the stratified medium ensure, by means of pressure forces, a transfer of the momentum almost without a transfer of heat, so that in the absence of turbulence the $\alpha$ values can be considerably less than unity. The nature of the dependence of the ratio of the coefficients of turbulent exchange on the stratification parameters in Fig. 3, in our opinion, can be related to the weak intensity of turbulence in the thermocline and the predominant influence of internal waves here on the statistical regime of small-scale fluctuations of hydrophysical fields.

We take the opportunity to express appreciation to specialists of the SDB OT headed by V. I. Fedonov and V. A. Kolesov, ensuring the carrying out of microstructural measurements, and V. Ya. Kogan, a specialist of the Pacific Ocean Institute Far Eastern Scientific Center USSR Academy of Sciences, who had the kindness to supply measurement data on the vertical flow velocity profile.

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[98-5303]

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CSO: 1865

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# INVESTIGATION OF THE SURFACE LAYER OF EVAPORATING SEA WATER BY THE OPTICAL INTERFEROMETRY METHOD

Moscow IZVESTIYA AKADEMII NAUK SSSR, FIZIKA ATMOSFERY I OKEANA in Russian Vol 15, No 10, 1979 pp 1067-1075

[Article by K. N. Fedorov, V. L. Vlasov, A. K. Ambrosimov and A. I. Ginzburg, Institute of Oceanology, submitted for publication 21 July 1978, resubmitted after corrections 22 December 1978]

Abstract: This paper presents the results of direct optical-interferometer measurements of the vertical profiles of density and temperature in a thin surface layer of sea and distilled water under conditions of evaporation and cooling from the free surface. The vertical salinity profiles computed from these profiles for the first time give a factual idea concerning the salinity increase $\Delta S$ and its vertical distribution in the boundary layer of sea water during evaporation. The form of these profiles and the thickness of the layer of increased salinity determined from them and the magnitude of the increased salinity at the surface coincide well with the theoretical estimates. The article gives a detailed description of the laboratory apparatus used, whose principal component is a laser photoelectric interferometer. The measurement method is discussed.

[Text] 1. Introduction. Until very recently investigations of the structure and convective instability of the boundary layer in sea water at the free surface have met with an insuperable difficulty, associated with the impossibility of measuring its increased salinity by contact methods, this increased salinity resulting from evaporation $\Delta S$ as a result of the exceedingly small thickness of this layer. Although the patterns of cooling and convective instability, and also the structure of the boundary layer in fresh water at the present time have been adequately well studied [1, 2], the problem of to what degree the patterns of development of convection in fresh water can be applied to saline water and what might be the contribution of salinity to the overall convective instability of the thermohaline boundary layer still remains unclear. Only recently the first plausible conclusions were drawn concerning the contributions of cooling and increased salinity to instability of the boundary layer under different conditions and the first realistic estimates of $\Delta S$ for sea water were obtained [3]. The basis for these conclusions and the estimates of $\Delta S$ was laboratory measurements of the temperature profiles and the frequency of thermals in sea water, and also extrapolation of the physical patterns of development of convection in fresh water to the case of sea (saline) water. However, the necessity for direct measurements of $\Delta S$ did not thereby disappear, but on the contrary, became still more essential, if for no other reason than that the conclusions drawn and the estimates might be confirmed or refuted. It was decided to have recourse to the optical interferometry method, which, in our opinion, at the present time is the sole method capable of ensuring a spatial resolution close to that desired without the introduction of any perturbations in the structure of the investigated layer. Below we give a description of the laboratory apparatus used and present the results of this experiment.

2. Laboratory apparatus and measurement method. A block diagram of the laboratory apparatus for investigating the fine structure of the surface layer of water by the optical interferometry method is shown in Fig. 1. The apparatus is based on the submersible laser photoelectric interferometer developed at the Institute of Oceanology USSR Academy of Sciences, intended for direct in situ measurement of the thin vertical structure and turbulent fluctuations of the density of sea water in the ocean. In the laboratory apparatus a parallel beam of light, emanating from the interferometer, passes through the investigated fluid, situated in a cell whose end walls are plane-parallel windows of optical glass, polished to the 14th accuracy class. The dimensions of the cell (20 x 60 x 200 mm) were selected in accordance with the design peculiarities of the submersible interferometer, taking into account the high response of the instrument to the investigated effects. Due to the existing size restrictions it was not possible to ensure fully the heat insulation of the walls, which in this stage of the experiment made impossible a precise quantitative estimate of the heat flow through the free surface of the water cooling in the cell.

By means of photomultiplier diaphragms with a diameter of ~ 0.5 mm, light rays were "cut" from the parallel light beam. One of these rays passed directly through the investigated fluid, whereas another passed through a hollow metal tube with a diameter of 2 mm, filled with air, built in hermetically into the cell between its optical windows.

These light rays, interfering with the reference light beam in the interferometer, form the measurement and reference systems of interference bands respectively. In Fig. 1 these rays, for clarity, are shown one above the other, whereas in the apparatus they are both in the same horizontal plane.

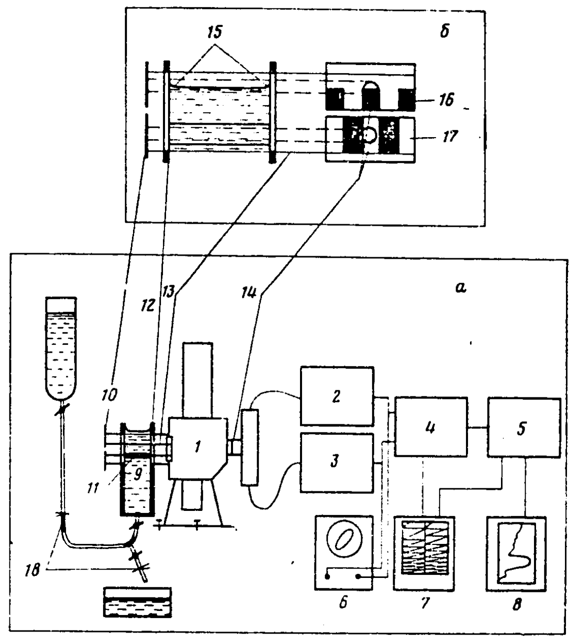


Fig. 1. Block diagram of apparatus for investigating the surface film by the optical-interference method (a) and schematic appearance of the measurement cell and two systems of interference bands (b): 1) submersible laser photoelectric interferometer; 2, 3) 1/3-octave filters (TOA-III); 4) analog measuring device; 5) digital reversing device; 6) S1-49 oscillograph; 7) N-327 automatic recorder; 8) KSP-4 automatic recorder; 9, 12) measuring cell; 10) interference mirrors; 11) tube with air; 13) light beam; 14) 1st and 2d photomultiplier diaphragms; 15) water meniscus; 16, 17) measurement and reference systems of interference bands respectively; 18) terminals

The reference system of interference bands was introduced for increasing noise immunity and accordingly the accuracy of dynamic optical-interference measurements under conditions of ordinary, nonthermostated and not vibroinsulated laboratory rooms [4, 5]. Due to the influence of destabilizing factors, measurements under such conditions until now have been completely impossible even in a static regime.

The reference and measuring systems of interference bands were organized in the apparatus in such a way that the destabilizing factors (for example, temperature and vibration fluctuations) cause an identical drift and fluctuations in both systems, but the useful effect is reflected only in their relative shift.

The relative shift between the measuring and reference systems of interference bands is directly proportional to the changes in the refractive index (density) of the investigated fluid caused by changes in its temperature T or salinity S. The optical difference in the paths between the first and second rays $\Delta z$ is associated with changes in the refractive indices of water $\Delta n(\Delta T, \Delta S)$ and air $\Delta n'(\Delta T)$ and the value of the relative shift of interference bands $\alpha$ by the expression

$$\Delta z = l[\Delta n(\Delta T, \Delta S) - \Delta n'(\Delta T)] = (\lambda/2)\alpha, \tag{1}$$

where $l$ is the geometrical length of the path of a parallel light beam, equal to the distance between the windows in the cell; $\lambda$ is the length of the light wave, in our case equal to $0.6328\,\mu m$.

Since for air the coefficient $dn'/dT = -9 \cdot 10^{-7}$ degree$^{-1}$, that is, more than two orders of magnitude less than the corresponding coefficients for water $dn/dT = -12.1 \cdot 10^{-5}$ degree$^{-1}$ and $dn/dS = 18.2 \cdot 10^{-5}$ $1^{o}/oo$, the second term in expression (1) (with an error less than 1%) can be neglected and expression (1) assumes the form:

$$\Delta z = l\Delta n(\Delta T, \Delta S) = (\lambda/2)\alpha, \tag{2}$$

hence

$$\Delta n(\Delta T, \Delta S) = (\lambda/2l)\alpha. \tag{3}$$

As follows from (3), the accuracy in measuring the relative changes in the refractive index $\Delta n(\Delta T, \Delta S)$ and accordingly the changes in salinity $\Delta S$ and temperature $\Delta T$ with a given length of the measurement base $l$ will be determined only by the accuracy in measuring the relative shift $\alpha$ of the interference bands.

Until recently the relative shift of the interference bands was determined by subjective visual methods (and only in a static regime) with an accuracy of approximately 1/20 the interference band [6]. In the described apparatus for the first time use was made of the noise-immune photoelectric method for measuring the relative shift of the interference bands (in static and dynamic regimes) proposed by one of the authors [7]. A modification of this method [8] made it possible to realize, as was indicated by experimental-theoretical investigations [4,5] in ordinary laboratory rooms, an accuracy not worse than 0.005 of the interference band. This modification involves a scanning of the interference pattern in conformity to a linear sawtooth law with a rigorously determined amplitude and measurement of the phase difference of the first harmonics of the photocurrent, proportional to the sought-for relative shift of the interference bands.

We note that the mentioned increase in accuracy and noise immunity of optical-interference measurements is of general interest for different fields of science and technology in which it is necessary to make measurements of small changes in physical parameters: concentrations of solutions in molecular physics [9], shock waves with flow around bodies in gas dynamics [10], the refractive index and density of sea water in oceanology [11], etc.

It follows from formulas (2), (3), with the values dn/dT and dn/dS taken into account, that in our case with $l$ = 2 cm and an error in determining $\alpha$ of about 0.005 the minimum errors in measuring $\Delta n$, $\Delta T$ and $\Delta S$ could be $0.8 \cdot 10^{-7}$, $7.5 \cdot 10^{-4}$ °C and $4 \cdot 10^{-4}$ respectively. In actuality, the accuracy realized in our apparatus is determined by the response of the recording apparatus used. For the reversing digital recording apparatus it is equal to 0.1 of the band, whereas for the analog measuring device it is not worse than 0.025 of the band. Accordingly, the use of a reversing digital recording unit gives for $\Delta n$, $\Delta T$ and $\Delta S$ accuracies of $1.6 \cdot 10^{-6}$, $1.5 \cdot 10^{-2}$ °C and $8 \cdot 10^{-3}$ °/oo, whereas the corresponding values for the analog measuring device are $4 \cdot 10^{-7}$, $4 \cdot 10^{-3}$ °C and $2 \cdot 10^{-3}$ °/oo respectively.

The reversing digital recording unit is intended for measuring the values of the whole and fractional part of the relative shift of the interference bands (of any sign), whereas the analog measuring unit is for measuring only the fractional part of the shift in the limits of one band. In this case in the digital unit there is an automatic return to zero with a shift each ten bands, and in the analog unit -- with a shift by one band. The measuring system contains an oscillograph (Fig. 1,a) for visual monitoring of the amplitude and phase shift of the signals from a Lisssajou figure.

The method for measuring the profiles of the refractive index and density in the surface layer was as follows. Using three adjusting screws (Fig. 1, a) the fluid surface in the cell was set parallel to the light beam emanating from the interferometer. Small clamps were used in selecting the necessary rates of inflow and outflow of fluid from the cell. Then the entry and exit tubes were closed by two clamps. At the time that the measurements began the clamp was removed from the release line and the fluid level dropped at a stipulated rate. In this process the surface layer moved relative to the light ray and there was registry of the profile of the refractive index corresponding to the movement of the light ray through the layer in an upward direction. With emergence of the ray from the water into the air, which was noted from the disappearance of the electric signal on the oscillograph (see below), the exit tube was closed by a clamp and the clamp was removed from the entry tube. The fluid level again increased and this corresponded to registry of the profile with movement of the ray in a downward direction.

The relative changes in density $\Delta\rho$ of distilled and saline (35°/oo) water, and also the temperature of the distilled water in the surface layer, were determined by means of scaling of the measured values of relative changes in the refractive indices of saline $\Delta n_s(\Delta T, \Delta S)$ and distilled $\Delta n_0(\Delta T)$

water using the following working formulas:

$$(1/\rho_0)\Delta\rho(\Delta T)=2{,}75\Delta n_0(\Delta T), \tag{4}$$

$$(1/\rho_0)\Delta\rho(\Delta T,\ \Delta S)=2{,}64\Delta n_S(\Delta T,\ \Delta S), \tag{4a}$$

$$\Delta T=\Delta n_0(\Delta T)/(dn/dT)|_{T_0}, \tag{5}$$

$$(dn/dT)|_{T_0}=-10^{-5}[12{,}1-0{,}36(30-T_0)],\ \text{град}^{-1}. \quad (\text{degree}^{-1}) \tag{6}$$

Here $T_0$ is the mean temperature of the distilled water below the "surface film" (at the measurement time). Formulas (4) were derived by differentiation of the well-known Lorentz-Lorenz formula (which is correct on the assumption of small, not greater than $10^{-2}$-$10^{-3}$, changes $\Delta n$ and $\Delta\rho$) and the assumption of the values $n_0 = 1.33$, $n_S = 1.34$ ($\rho_0 = 1$ g/cm$^2$) in them. The correctness of formula (5) with small $\Delta n$ and $\Delta T$ is obvious. Formula (6) was derived by us by interpolation of tabulated values of the refractive index of distilled water in the interval 20-30°C; these values were given only each 5°C [12].

The salinity profile in the surface water layer ($S \approx 35^{\circ}/oo$) was determined by subtraction of the profiles of change in the refractive index of distilled and saline water, measured under one and the same conditions (with identical air humidity and an identical temperature difference between the water and air). The working formula for the computations has the form:

$$\Delta S = \left[\Delta n_S(\Delta T,\ \Delta S) - \Delta n_0(\Delta T)\frac{dn_S/dT|_{T_S}}{dn_0/dT|_{T_0}}\right] \Big/ \left.\frac{dn_S}{dS}\right|_{T_S}, \tag{7}$$

$$(dn_S/dT)|_{T_S}=-10^{-5}[13-0{,}24(30-T_S)],\ \text{град}^{-1}, \quad (\text{degree}^{-1}) \tag{8}$$

$(dn_S/dS)|_{T_S} = 18.2\cdot10^{-5}(^{o}/oo)^{-1}$ with $S \approx 35^{o}/oo$ and $T_S$ = 20-30°C. Here $T_S$ is the mean temperature of saline water below the "surface film" (at the time of measurement).

The principal assumption made in the derivation of formula (7) is that there is presumed to be an identity of the temperature profiles in distilled and saline water with one and the same external conditions of heat and mass exchange. As indicated by the experimental data in [3], this assumption is correct in the above-mentioned temperature range. In the derivation of formula (7) no approximations of a mathematical nature were made.

Now we will discuss the problem of the minimum distance from the water surface at which there can still be measurements by the optical interference method and also the problem of integration (averaging) of the measured values of the linear profile due to the finite thickness of the light ray, especially with its emergence at the water and air discontinuity. Figure 1,b schematically shows the moment of emergence of the light ray at the discontinuity between the water and the air and the interference pattern observed in this case. In the upper part of the circular photomultiplier diaphragm, which corresponds to the passage of part of the light ray in the air, interference bands are absent. This occurs due to the appearance of an additional wedge of the optical difference which will then be observed in the water meniscuses, changing the interferometer adjustment. The photomultiplier in this case reacts to that part of the variable light flux of the modulated pattern which no longer originates from the entire diaphragm but only from that segment of the diaphragm where the interference bands still remain. As a result, the signal amplitude in the measurement channel gradually drops, which in every case was observed directly on the oscillograph from the Lisssajou figure. Then comes a moment when it falls into the zone of nonresponse of the digital reversing and analog measuring devices which we developed. The amplitude dynamic range in which there is still no additional error in measuring the difference in signal phases (that is, relative to the shift of the interference bands) is not less than 50 db, that is, about 1/300 of the maximum signal strength. Since in adjusting the interferometer it was not always possible to obtain a maximum signal strength, we will use a dynamic range which is an order of magnitude less (that is, 1/30). And since the signal amplitude is proportional to the light flux, which in turn is proportional to the area of the photomultiplier diaphragm segment in which the interference bands are still present, the height of the segment, whose area is 30 times less than the area of the entire diaphragm, is approximately 0.1 of its diameter. Thus, the minimum distance from the water surface at which it is still possible to make measurements by the optical-interference method does not exceed 0.05 mm.

The fundamental advantages of dynamic measurements using a light ray, for example, the temperature profiles, in comparison with ordinary measurements with miniature temperature sensors, are an absence of distortions of the temperature profile due to: a) inertia of heat exchange between the sensing element and the medium, b) heat exchange between the sensing element and its holder, having another temperature, c) different heat exchange between the parts of the sensing element and accordingly between the water and air with arrival of the sensor at the discontinuity between them.

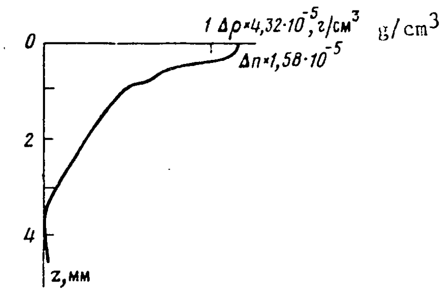


Fig. 2. Profile of measurement of the refractive index (density) in the boundary layer in fresh water, demonstrating distortion in the uppermost part due to averaging over the area of the light ray section.

Now we will examine the qualitative picture of averaging of the measured linear segment of a profile by a ray of finite thickness, especially this averaging with emergence of the ray at the water-air discontinuity. For this purpose we will visualize a narrow vertical slit diaphragm of the photomultiplier with the height 2R and a corresponding light ray. Assume that part of this ray emerged from the discontinuity between the water and air at the height $\Delta z$. Then on the basis of the integral mean theorem, the coordinate $z_0$ of the measured value of the refractive index with a linearity of the $\Delta n(z)$ profile no longer will correspond to the center of the diaphragm, and is equal to $z_0 = R - \Delta z/2$. Thus, we see that with emergence of the ray from the water-air discontinuity its movement by $\Delta z$ corresponds to a change in the measurement coordinate by $\Delta z/2$. In other words, from the moment of contact of the ray with the surface the equivalent velocity of vertical movement of the light ray decreases in a jump by a factor of 2. However, since in the case of a circular diaphragm the averaging occurs in all the vertical planes of the segment, that is, over its area, the change in velocity does not occur in a jump, but smoothly, beginning with the distance between the ray axis and the water surface, equal to the radius (0.25 mm in our case). This velocity change leads to a nonlinear bend in the profile at the end of measurement at the surface itself. The mentioned phenomenon was repeatedly observed in an experiment with an extended record of the profiles obtained using an N-327 high-speed automatic recorder from the analog measurement unit. Figure 2 shows the profile registered near the surface; it is easy to see the mentioned phenomenon. We note that this phenomenon should be observed when making measurements with any sensor of finite dimensions.

3. Measurement results. We obtained about 100 records of profiles of the refractive index in fresh and sea water ($S \approx 35^o/oo$) with different values of the heat flow through the water-air discontinuity. Figure 3, incorporating the results of all measurements taken together, shows the dependence of the values $\Delta n\,|_{z=0}$ for fresh and sea water for different values of the temperature difference between the water and air, both positive and negative. Along the x-axis we have also given the approximate values of the total heat flow through the water-air discontinuity, computed from the vertical temperature gradients in the linear segments of the registered profiles. The scatter of points observed in Fig. 3 in part has a random character caused by the nonstationary nature of the observed profiles and the passage of thermals. However, a systematic discrepancy is discovered: all the points for sea water lie somewhat above the points for distilled water, which is evidence of an additional contribution of increased salinity to the increase in density of the thin surface layer.

The graph in Fig. 3 confirms that with some negative difference in the temperatures between the water and air the "cold" film disappears and is replaced by a warm film in which the density of the surface layer must be decreased. This comes about in a case when the effect of contact heat exchange exceeds the total effect of increased salinity and the heat loss on evaporation. In this case in the fresh water there is a general increase in density with depth, corresponding qualitatively to the earlier recorded temperature change in the surface layer with a "warm" film [13]. In sea water, as a result of increased salinity due to evaporation it is possible to expect an inversion change in density in the very thin surface layer against a background of this general increase in density with depth. Measurements of the $\Delta n(z)$ profile in saline water for the time being have not yet been made in the presence of a warm film.

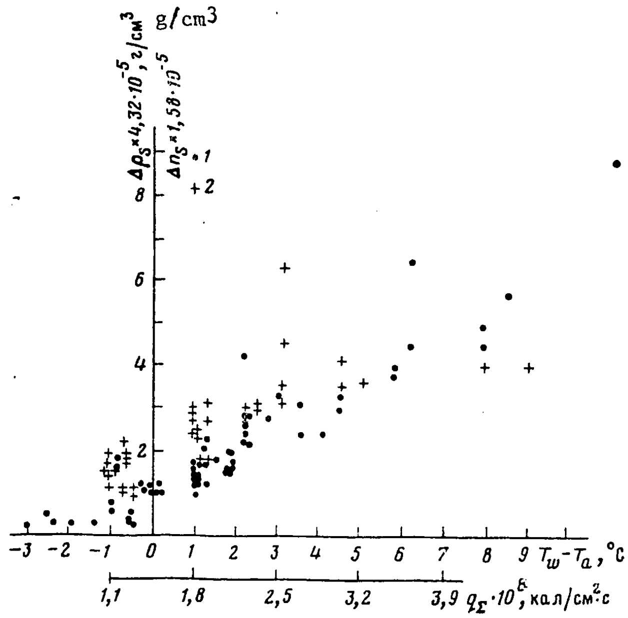


Fig. 3. Dependence of change in the refractive index (density) in the surface layer on the temperature difference between water $T_w$ and air $T_a$. For greater clarity, at the bottom we have given the scale of sample values of the heat flow through the water-air discontinuity: 1) fresh water, 2) sea water ($S \approx 35^o/oo$).

Figure 4 shows examples of the profiles of change in the refractive index $\Delta n_S$ (density $\Delta\rho_S$) in sea water (denoted by the figure 1) under "cold" film conditions registered in three experiments. Using these profiles, on the basis of formulas (7) and (8) it was possible to obtain the profiles of increased salinity $\Delta S(z)$ shown in these same figures for the surface layer of sea water (denoted by the figure 3). The vertical profiles of temperature decrease $\Delta T(z)$ (denoted by the figure 2) were obtained by measuring the refractive index (density) in distilled water under the very same conditions as in sea water. The profile $\Delta n_S(z)$ (or $\Delta\rho_S(z)$) in Fig. 4 corresponds to the total heat flow q through the water-air discontinuity of about 0.15 cal/cm$^2$min at a water temperature of 27.2°C. With respect to its form and parameters this profile is very similar to the theoretically obtained profile $\Delta\rho_S(z)$ for close conditions ($T_w$ = 30°, S = $35^o/oo$, q = 0.2 cal/cm$^2$min) [3]. The value $\Delta S \approx 0.15^o/oo$ obtained in an experiment is also close. A corresponding theoretical estimate for more intensive conditions of heat and mass exchange gives $\Delta S \approx 0.32^{\circ}/oo$. Measurements also show that the layer of increased salinity is considerably thinner than the cooled layer. In Fig. 4,b increased salinity is conspicuous only in a surface layer with a thickness not greater than 1 mm. Source [3] gives a theoretical estimate of the measure of thickness of this layer of about 0.3-0.5 mm.

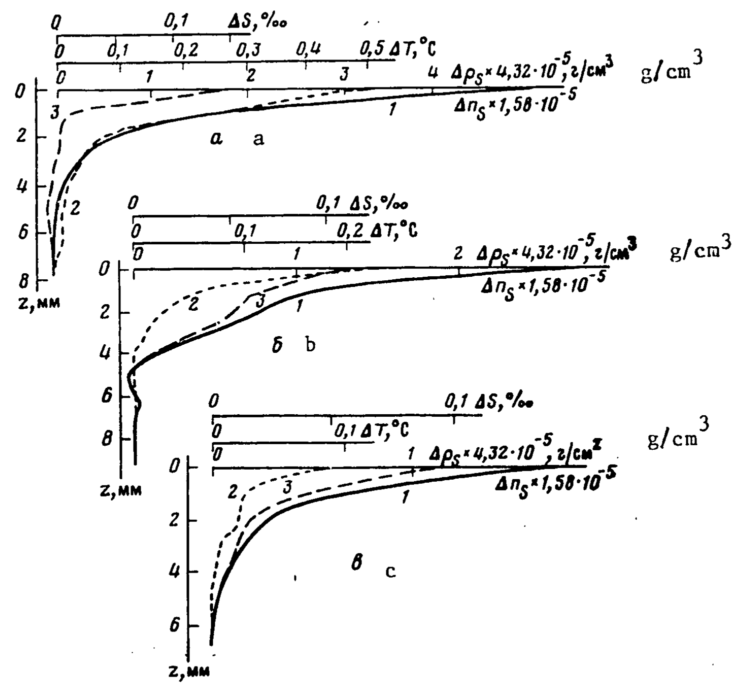


Fig. 4. Example of vertical profiles in experiment with $\Delta T_{wa} > 0$ (a, b) and with $\Delta T_{wa} = -1°C$ (c): 1) $\Delta n_S(z)$ or $\Delta\rho_S(z)$ in saline water (a -- with $q \approx -0.15$-$0.2$ cal/cm$^2$min, $T_w = 27.2°C$), 2) $\Delta T(z)$ in distilled water with approximately these same values q, $T_w$ and $T_a$, 3) $\Delta S(z)$ (the profile was computed using formulas (7) and (8)). Distortions due to thermals are shown on the profiles in Fig. 4, b and c.

The profiles in Fig. 4,b and c were distorted by "thermals" carrying the water downward; this water was not only cooled, but had increased salinity. Therefore, the attractive impression is created that on the profiles illustrated in these figures the layer of increased salinity extends deeper.

The profiles in Fig. 4,c, obtained with a water temperature which was 1°C lower than the air temperature, nevertheless have a surface layer of increased density because the total effect of increased salinity and cooling due to evaporation considerably exceeds the effect of a decrease in density as a result of contact with the warmer air. However, the increased salinity in this case does not exceed 0.08°/oo. We note that the measurements made not only confirm well the estimates and conclusions presented earlier in [3], but also demonstrate the extremely interesting possibilities of the optical-interference method developed by V. L. Vlasov and A. N. Medvedev in such fine measurements, which this investigation required. These possibilities were still not realized completely in the experiments described above. We hope to realize them in further experiments for obtaining the quantitative dependence of $\Delta S$ on the conditions for heat and mass exchange at the discontinuity.

In conclusion the authors express appreciation to I. A. Filippov for developing and fabricating the cell and a number of fine attachments for the laboratory apparatus.

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EXPERIMENTAL STUDY OF INTERNAL WAVES IN OCEAN BY REMOTE METHODS

Moscow DOKLADY AKADEMII NAUK SSSR in Russian Vol 249, No 4, 1979 pp 980-983

[Article by B. A. Nelepo (Academician Ukrainian Academy of Sciences) and Yu. M. Kuftarkov, submitted for publication 11 September 1979]

[Text] In the problem of investigating the world ocean from space one of the timely problems, according to our concepts, is the recognition of "images" of internal gravitational waves from infrared (IR) photographs of its free surface. Long internal waves cause slowly changing currents in the upper quasihomogeneous layer, as a result of which there is a change in the thermodynamic state of the free surface, on which, in essence, the characteristic thermal emission of the ocean in the IR spectral range is formed. Available empirical information and theoretical concepts make it possible to discriminate the principal physical mechanisms associated with the influence of internal waves on radiation temperature $\tau_{rad}$.

1. The transformation of the high-frequency spectral region of surface waves by currents in long waves exerts a significant influence on the thermal structure of the thin (1-5 mm) cold layer at the free surface of the ocean. It was demonstrated in [1] that the greatest contribution to the temperature drop and heat flux in the cold layer is from short capillary waves. Thus, the effect of internal waves at the free surface of the ocean can be manifested, for example, in variations of the thermodynamic temperature T through the reaction of the high-frequency part of the spectrum of wind waves to the variable current induced by internal waves. In the last analysis this leads to $\tau_{rad}$ variations.

2. In convergence zones the velocity fields of internal waves at the free surface accumulate surface-active substances causing changes in the optical properties of ocean water, which results in changes in the reflection and absorption coefficients.

Experimental investigations of the spectral reflection coefficient in the region of wavelengths 9-12 $\mu$m indicated that for sea water covered by a petroleum film the value of this coefficient is 5-10 times greater than for the clean sea water [2]. Variations of the mentioned coefficients as a function of the level of concentration of surface-active substances lead to variations of the emission coefficient $\epsilon$ , and as a result, to a change in the temperature $\tau_{rad}$.

3. Changes in the area of the free surface of the ocean scanned by an IR radiometer are unambiguously related to variations of its mean square slope $\hat{\nabla}\zeta^2$. Transformation of the spectrum of surface waves caused by a long internal wave [3-7] leads to variations of the mean square slope of the free surface, which in turn exerts an influence on $\tau_{rad}$.

The significance of the enumerated factors in the effect of internal waves on radiation temperature of the ocean surface varies in dependence on meteorological conditions and the degree of ocean contamination.

In the case of small slopes of the free surface of the ocean the mathematical expression for temperature variations $\tau_{rad}$ in the near-IR spectral region with a sufficient accuracy can be represented by the expression

$$\delta\tau_p = \delta\tau + \frac{\kappa\tau^2}{h\nu}[\delta\epsilon + \tfrac{1}{2}\delta\overline{\hat{\nabla}\zeta^2}],$$

[p = rad] where K, h are universal constants, $\nu$ is the mean frequency of the working range of the IR radiometer.

Table 1

| Instrument | Number of series | Depth, m | Duration, in hours | Discreteness, minutes | Number of terms in series |
|---|---|---|---|---|---|
| IR radiometer | 1 | 0 | 7.93 | 0.62 | 772 |
| RDT-10 | 2 | 50-6C | 7.93 | 0.62 | 772 |
| RDT-10 | 3 | 60-70 | 7.93 | 0.62 | 772 |

Variations in the parameters $\tau$, $\epsilon$ and $\hat{\nabla}\zeta^2$ under the influence of internal waves lead to variations in radiation temperature, which creates the possibility of indication of internal gravitational waves on the basis of the characteristic thermal emission of the free surface of the ocean.

On the expedition of the 18th voyage of the scientific research ship "Akademik Vernadskiy," carrying out investigations in the North Atlantic under the international program "JASIN-78," an experiment was carried out whose purpose was determination of the interrelationship between internal waves of the seasonal thermocline and the radiation temperature of the free surface. The experiment was methodologically carried out in three variants: I -- ship at drift, II -- ship at anchor, III -- ship in movement. Here we briefly present the method for carrying out the experiment in variant I.

Observations of the field of internal gravitational waves were carried out from a drifting ship using an antenna of three bundles of distributed temperature sensors (RDT sensors), spatially distributed. Two bundles were lowered from the stern and tank of the vessel; the third was placed on a buoy at a distance of 100 m from the middle of the ship, perpendicular to its side. The bundles of sensors were formed of links of different scales and occupied the upper quasihomogeneous layer of the ocean and the seasonal thermocline. The distribution of sensors was as follows. The bundle at the ship's stern consisted of seven 10-m temperature sensors (RDT-10) and one with a length of 100 m. Three sensors (two 10 m in length and one 50 m in length) were lowered into the ocean from the ship's tank. The bundle situated on the buoy consisted of three pairs of sensors: 50, 25 and 10 m in length. In order to determine the drift of the vessel relative to the water a bundle of automatic current recorders was suspended from the stern; they occupied the upper 70-m ocean layer and consisted of five "Disk" instruments and three BPV instruments.

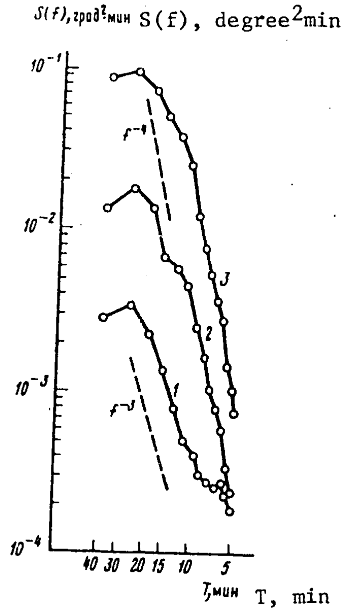


Fig. 1.

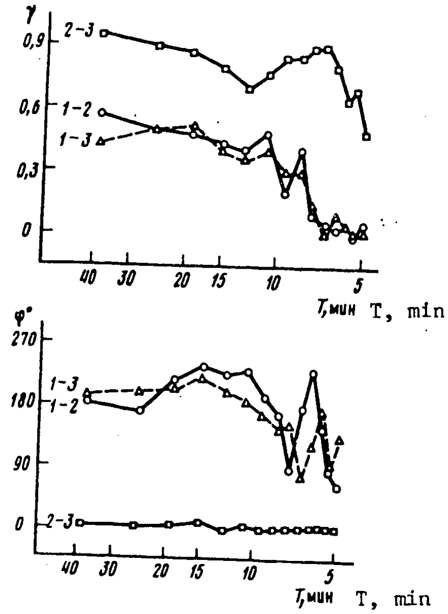


Fig. 2.

This scheme for the placement of the distributed temperature sensors made possible a detailed investigation of the vertical structure of the temperature field and a determination as to whether we are dealing with a random set of internal gravitational waves or with mesoscale turbulence.

In order to compute the mean profile of the Brent-Väisälä frequency characterizing the field of internal waves measurements were carried out using "Istok" (STD) instruments and a descending fine structure probe. Directly at the free surface observations were made of the microstructure of the temperature field using a floating-up probe [8].

Measurements of the radiation temperature of the ocean surface were made using an IR radiometer (in the range 8-12$\mu$m) with a time constant of 3 sec and a response not poorer than 0.03°C. The radiometer was mounted on a boom at the ship's prow and was oriented vertically downward. The angle of view of 5° ensured averaging of the radiation temperature in a circle with a radius of 1 m. In the analysis use was made of data from an eight-hour measurement interval during evening and nighttime -- the most favorable times for observations of radiation temperature of the ocean surface.

Table 1 gives the characteristics of some series of measurements subjected to statistical processing. Figure 1 shows the spectral densities of temperature in the thermocline (2, 3) and the radiation temperature at the free surface of the ocean (1). All spectra in the range of time scales $T > 10$ min are characterized by a rather steep ($f^{-3}$ - $f^{-4}$) decrease from the low to the high frequencies, which gives basis for postulating a wave character of the investigated phenomenon.

An identification of wave movement can be accomplished best on the basis of a mutual analysis of temperature fluctuations in the thermocline (series 2 and 3). Figure 2 shows the coherence spectra $\gamma$ and the phase shift $\varphi$ between the corresponding series. The evaluation of coherence between series 2-3 is very high, much greater than the significant coherence values (95% guaranteed probability). The insignificant dependence of the phase shift on frequency and the high coherence not only confirm the wave nature of the investigated process, but also give basis for saying that in this case oscillations of the first mode predominate.

The degree of interrelationship between internal waves and $\tau_{rad}$ at time scales from 10 to 40 minutes is illustrated by the coherence spectra and phase spectra 1-2 and 1-3. If series 1,2 and 1,3 were uncorrelated, with a number of degrees of freedom equal to 30 the value of the coherence evaluations (95% guaranteed probability) would not exceed the level of random errors (0.36). The stability of the phase shift in periods from 40 to 10 minutes also indicates a correlation of the temperature fluctuations in the thermocline and at the free surface of the ocean.

We will emphasize an important result which follows from an analysis of the phase spectrum. The fluctuations of effective temperature in the thermocline (with an accuracy to the registry and processing of data) are almost in antiphase with the radiation temperature of the free surface of the ocean. This experimental fact merits great attention since it gives basis for assuming that on the basis of IR photographs of the free surface of the ocean it is possible not only to reconstruct the scales of internal waves but also to determine convergence and divergence zones.

We note in conclusion that at the present time there are only a few studies [4,5] on experimental investigation (in the optical range) of internal waves from space and from aboard a flight vehicle. The physical ideas which served as a basis for these studies are related to transformation of the spectrum of surface waves in the field of a current induced by a long internal wave. In this sense the approach to the problem of indication of internal waves used here has a direction in common with these investigations.

The authors consider it their pleasant duty to thank Academician A. M. Obukhov for cooperation in carrying out the experiment and discussing the results.

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EFFECT OF LIGHT SCATTERING BY SEA WATER ON OPERATION OF A PHOTOELECTRIC SHADOW INSTRUMENT

Moscow OKEANOLOGIYA in Russian Vol 19, No 5, 1979 pp 915-918

[Article by Yu. N. Kalugin, B. F. Kel'balikhanov, E. I. Krasovskiy and B. V. Naumov, Institute of Oceanology, submitted for publication 10 February 1978]

Abstract: A study was made of the influence of sea water scattering of the light flux emitted by a photoelectric shadow instrument on its readings. It is shown that the really observed fluctuations of light scattering by sea water and also the changes in the scattered light flux with submergence of the instrument into the water do not cause a significant change in the response threshold. Scattering fluctuations of about $10^{-2}$% or more can be registered by the instrument as a useful signal which must be taken into account in the interpretation of the measurement results.

[Text] Photoelectric shadow instruments are used in oceanological investigations for measuring fluctuations of the refractive index [2, 8]. The most commonly used variants are lens and mirror instruments with a parallel path of the rays within the volume of the medium to be analyzed [2, 5, 9]. The real media studied using this class of instruments scatter part of the light flux transmitted through the volume to be analyzed. Usually the extent of the volume to be analyzed is small in comparison with the length of the free path of a photon in the investigated medium, that is, multiple scattering is quite small and it can be assumed that lens instruments sense the light flux scattered at small angles (relative to the incident flux), which is usually a value 1'-10'. In mirror instruments, in addition to the light scattered at small angles to the incident flux, a light flux scattered at angles $180° \pm \gamma$ is also incident on the photodetector.

The presence of a scattered light flux leads to an additional illumination of the photodetector and an increase in the response threshold caused both by an increase in shot noise and by fluctuations of the scattering index which can cause the appearance of an additional signal at the instrument output. Below we will evaluate the mentioned influence of scattering of the light flux emitted by the instrument on the readings of the photoelectric shadow instrument when it is used for measuring fluctuations of the refractive index [10].

The measurement of the scattering function $\beta(\gamma)$ in the region of small angles involves great difficulties. In a number of studies, such as [3, 7], experimental data are cited for the region of angles 1-10° and the values of the function for lesser angles are extrapolated [7, 11].

Sources [4, 6] gave experimental data for the range of angles 0.1-160°. According to the data in these studies and [7], which gave an analysis of the extremal functions characterizing extreme hydrooptical situations, the scatter of really measured values of the function for an angle of 1.5° falls in the range 0.35-10.7 $m^{-1}$, whereas extrapolation to 0° leads to values 1.04-31.7 $m^{-1}$. In measurements of the functions the maximum of spectral response of the instrument for measuring scattering was in the green part of the spectrum. The experimental values of the scattering function for an angle of 180° are $(2.7\text{-}7.8)\cdot 10^{-4}$ $m^{-1}$, that is, the minimum is three orders of magnitude less than the corresponding values of the function for an angle of 0°. Accordingly, the effect of scattered light on mirror instruments for all practical purposes is determined completely by the value of the scattering function at small angles. The difference in the scattering effect on mirror and lens instruments is caused only by double the length of the light beam path in the analyzed volume of the mirror instrument in comparison with the lens instrument. The approximation $\beta(\theta) = \beta(0°)$ can be used in evaluating the influence of scattering. The results of numerous measurements of the scattering function in different areas of the world ocean [7,4] show that the dependence $\ln \beta(\theta)$ in the region of small angles is close to linear. Therefore, in [7] the extrapolation formula has the form

$$\beta(\theta) = \beta(0°) \exp \theta (B + C\theta).$$

For the values of the extremal functions cited in [7], B = -41.6; $C \ll B$, that is $\beta(\theta) \approx \beta(0°) \exp \theta B$. The error in the approximation $\beta(\theta) = \beta(0°)$ to the extrapolation function $\beta(\theta) = \beta(0°) \exp \theta B$ can be evaluated (after expansion of the function $\beta(0) \exp (B\theta)$ into a Taylor series) by the sum of terms of the series

$$\Delta\beta(\theta) \approx \beta(0)\, B\theta \left(1 + \frac{B\theta}{2!} + \frac{B^2\theta^2}{3!} + \ldots\right)$$

The error in the approximation is not greater than 1.1% for $\theta \leqslant 1'$ and not more than 11% for $\theta \leqslant 10'$.

When using this approximation we assume that then the scattering index in the angle interval $0-\gamma$ [3] is

$$b = 2\pi\int_0^{\gamma}\beta(\theta)\,\sin\theta\,d\theta \approx \gamma^2\beta(0). \tag{1}$$

The scattered light flux received by the radiation detector is

$$F_{sc} = (1 - e^{-bz_0})F \approx \pi\gamma^2 z_0\,\beta(0)F, \tag{2}$$

where $z_0$ is the extent of the analyzed volume of the medium in the direction of the instrument optical axis, F is the light flux entering into the analyzed volume; the approximation (2) is correct with the usually satisfied condition $bz_0 \ll 1$.

In shadow instruments part of the light flux arriving in the receiver is cut off by a blade and the photodetector receives the transmitted part of the light flux $F_{tr}$, in the absence of optical inhomogeneities in the medium constituting a hundredth of the incident flux (usually c = 0.02-0.50), that is, $F_{tr} = cF$. Since the maximum attainable instrument response threshold, governed by the shot noise, is

$$\Pi_{thr} = kF_{tr}^{i}, \tag{3}$$

where k is a proportionality factor, $i \leqslant 1/2$ (the equality sign corresponds to linear modifications of the instrument [9]), the relative increase in the response threshold with placement of the instrument in the scattering medium is

$$\frac{\Pi_{thr}(F_{tr} + F_{sc}) - \Pi_{thr}(F_{sc})}{\Pi_{thr}(F_{tr})} = \frac{\pi i}{c}\gamma^2 z_0\,\beta(0^\circ). \tag{4}$$

With extremal, within the limits cited above, values of the parameters entering into (4) and $z_0 \simeq 1$ m, the relative increase in the threshold does not exceed 3%, that is, the increase in the response threshold caused by scattering is insignificant even with operation of the instrument in the most turbid waters of the world ocean.

The threshold value of the fluctuations of the light flux incident on the photodetector is

$$\Delta F_{thr} = \Pi/\xi\gamma F, \tag{5}$$

where $\xi$ is a coefficient taking into account the relative nonlinearity of the instrument with threshold values of the input effect; for linear modifications $\xi = 1$, $\Pi$ is the instrument response threshold, usually $\Pi = 10^{-2}$-$10^{-4}$ sec [9, 12].

With towing of the instrument through regions with a changing scattering index the fluctuations of the scattered flux $\Delta F_{sc}$ will be registered by the instrument under the condition $\Delta F_{sc} > \Delta F_{thr}$. From this condition, with (2) and (5) taken into account, it is possible to find the relative value of the fluctuations of the function $\Delta\beta(0°)$, leading to the appearance of a signal at the output exceeding the threshold level.

$$\frac{\Delta\beta(0°)}{\beta(0°)} > \frac{\Pi}{\pi\xi\gamma^3 z_0 \beta(0°)} \quad . \tag{6}$$

Computations on the basis of (6), with extremal values of the above-mentioned parameters, shows that the instrument is capable of registering fluctuations of the scattering index of about 0.02%, or, in absolute measure, fluctuations of the function $\beta(0°)$ of about $6\cdot10^{-3}$ $m^{-1}$.

Summary

1. The really observed fluctuations of light scattering by sea water and also changes in the intensity of the scattered light flux emitted by the instrument, with its submergence into the stratified sea water, do not cause a significant (by more than 2-3%) "parasitic" increase in the response threshold.

2. Fluctuations of the scattering index of about $10^{-2}$% or more can be registered by the instrument; this value must be attributed to the measurement error and must be taken into account in an interpretation of the research results.

3. In case it is necessary to increase the instrument response range it is necessary to take into account the considerable increase in the influence of scattering fluctuations.

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III. TERRESTRIAL GEOPHYSICS

ARTICLES ON SEISMICITY OF KIRGIZIYA

Frunze GEOLOGO-GEOFIZICHESKIYE OSOBENNOSTI I SEYSMICHNOST' TERRITORII KIRGIZII (Geological and Geophysical Features and Seismicity of Kirgiziya) in Russian 1978 signed to press 1 Aug 78 pp 2, 94

[Annotation and table of contents of collection of articles edited by Corresponding Member Kirgiz Academy of Sciences K. Ye. Kalmurzayev, Izdatel'stvo "Ilim," 105 pages]

[Text] In this collection of articles, for the first time for the territory of Kirgiziya, an attempt has been made to tie in the character of the observed geophysical fields to its seismicity. The authors examine problems relating to the deep geological structure of the Tien Shan as a whole and its individual seismically dangerous regions and also the possibilities of using regime observations of changes in the magnetic field and gas-hydrogeochemical characteristics of deep thermal waters in the detection of earthquake precursors. The publication is intended for geophysicists and geologists.

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APPARATUS, METHODS AND RESULTS OF SEISMIC OBSERVATIONS: INSTRUMENTATION

Moscow APPARATURA, METODY I REZUL'TATY SEYSMICHESKIKH NABLYUDENIY: SEYSMICHESKIYE PRIBORY (Apparatus, Methods and Results of Seismometric Observations: Seismic Instrumentation) in Russian Issue 12, 1979 signed to press 13 Jul 79 pp 2, 189

[Annotation and table of contents of collection of articles edited by Doctor of Technical Sciences Ye. S. Borisevich and Doctor of Physical and Mathematical Sciences D. P. Kirnos, "Nauka," 196 pages]

[Text] Annotation. This collection of articles includes papers devoted to instrumental seismology relating to the development, graduation and calibration of seismometric channels for regional observations and the registry of strong earthquakes in the near zone. The authors have investigated the reliability and accuracy of geophysical instrumentation. Methods for designing a seismograph as a complex oscillatory system are given. The collection of articles is intended for specialists in the field of seismology, seismometry and geophysical instrument making.

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UDC 528.56

LONG-TERM STABILITY OF INERTIAL GRAVIMETRIC INSTRUMENTS

Moscow DOLGOVREMENNAYA STABIL'NOST' GRAVIINERTSIAL'NYKH PRIBOROV (Long-Term Stability of Inertial Gravimetric Instruments) in Russian 1979, signed to press 21 Mar 79 pp 2, 113

[Annotation and table of contents from the book edited by Candidate of Technical Sciences I. A. Maslov, Izdatel'stvo "Nauka," 118 pages]

[Text] This collection of papers presents the results of investigations of the elastic sensing elements of gravimeters, tiltmeters, gravitational gradiometers. Sensors of small movements are examined. The noise in gravi-inertial measurements is interpreted and analyzed. This collection is intended for instrument specialists and also for specialists in the field of gravi-inertial measurements, gravimetry and seismology.

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## IV. ARCTIC AND ANTARCTIC RESEARCH

### GEOPHYSICAL RESEARCH IN THE ARCTIC AND ANTARCTICA

Leningrad TRUDY AANII: GEOFIZICHESKIYE ISSLEDOVANIYA V ARKTIKE I ANTARKTIKE (Transactions of the Arctic and Antarctic Scientific Research Institute: Geophysical Investigations in the Arctic and Antarctica) in Russian Vol 340, 1977 signed to press 4 July 1977 pp 2, 161-162

[Annotation and table of contents of collection of articles edited by Candidate of Physical and Mathematical Sciences A. I. Ol', Gidrometeoizdat, 168 pages]

[Text] Annotation. This collection of articles gives the results of investigations of terrestrial magnetism, the ionosphere and radio wave propagation on the basis of materials from geophysical observations in the Arctic and in Antarctica. Also considered is the influence of the interplanetary magnetic field on geomagnetic disturbance and circulation of the lower layers of the earth's atmosphere. The authors discuss some spatial-temporal regularities of the high-latitude ionosphere and also the results of computations of the rate of ion formation in the polar ionosphere. The papers contain recommendations on the choice of antennas for apparatus used in slant sounding of the ionosphere on ships and on the organization of short-wave radio communication on high-latitude paths. The collection of articles is of interest for a broad range of specialists in the fields of geophysics, radio engineering, as well as students and graduate students working in the above-mentioned fields.

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